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Biological Experiments: The Viking Mars Lander

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Biological interest in the exploration of Mars is briefly described as is the biological experiments package to be flown as part of the Viking 1975 lander payload.

INTRODUCTION

Current theories about the origins of terrestrial organisms are based on ideas of Oparin (1924) and Haldane (1928). They proposed that living systems were the result of stepwise processes by which simple compounds, present in the primitive atmosphere of the Earth, were gradually converted into more and more complex chemicals until, ultimately, replicating systems were produced. The Oparin-Haldane hypothesis, often referred to as the "theory of chemical evolution," has received much experimental support since the initial experiments of Miller and Urey (cf. Miller, 1953) in which several amino acids were produced from a mixture of methane, ammonia, water, and hydrogen after being subjected to electric discharges. It is now clear that a considerable number of organic compounds of biological interest, including amino acids, purines, pyrimidines, porphyrins, carbohydrates, and fatty acids, can be synthesized in the laboratory under conditions that are designed to simulate conditions on the primitive Earth (for reviews see Ponnampuruma and Gabel, 1968; Lemmon, 1970).

That chemical reactions leading to the formation of organic matter also take place beyond the Earth is supported by recent radioastronomical observations in which formaldehyde (Snyder *et al.*, 1969) hydro-

gen cyanide (Snyder and Buhl, 1970), and cyanoacetylene (Turner, 1970) have been detected in interstellar space. In addition, chemical analysis of meteorites has shown that many of them, notably the carbonaceous chondrites, contain a number of organic materials (Hayes, 1967; Hodgson and Baker, 1969). Recently, for example, Kvenvolden *et al.* (1970) identified sixteen amino acids, in racemic mixtures, as well as a wide spectrum of hydrocarbons in extracts of the Murchison meteorite.

SCIENTIFIC OBJECTIVES

From the biological point of view, the Viking 1975 mission might be regarded as a test of the Oparin-Haldane hypothesis. Mars is a planet whose early history was probably similar to that of the Earth (Shklovskii and Sagan, 1966) and whose present environmental conditions may be compatible with the maintenance of living organisms. Thus, the biological experiments aboard the Viking 1 spacecraft are primarily concerned with the question of whether chemical evolution on Mars took place, and, if so, whether the process reached a level of complexity characteristic of replicating systems. If reproducing organisms appeared on that planet in its earlier history, under less hostile conditions, it is not unreasonable to suppose that

biological processes of adaptation subsequently could have selected for organisms adapted to the prevailing local conditions on the planet as it gradually lost much of its early atmosphere. Biological evolution, having kept pace with changing conditions on Mars, may thus have yielded a stable biological community on that planet.

A very important corollary objective of the life scientist involved in planetary exploration is to obtain information about the chemical, biochemical, and structural attributes of nonterrestrial organisms. This is because all forms of terrestrial organisms appear to be so very similar in structure and function. They all contain the same stereoisomers of the same 20 amino acids; have the same fundamental type of genetic apparatus, consisting of nucleic acid made up of the same chemical residues; and have the same mechanisms of protein synthesis and nucleic acid synthesis. The uniformity of cellular structure, biochemical pathways, and chemical composition among terrestrial organisms makes it very probable that all organisms on this planet are derived from a single ancestral type. What is unknown at present is whether it is possible for other kinds of chemicals and chemical reactions to support living systems. Is it possible that on another planet, like Mars, chemical and biochemical evolutionary processes have produced organisms containing fundamentally different types of macromolecules? Is it necessary for a living system to code its hereditary information in the form of long chains of polynucleotides? Must replicating organisms rely upon proteins (consisting of long chains of polymerized L- α -amino acids) to serve as metabolic catalysts? Questions such as these are intriguing to biologists who seek an understanding of the truly fundamental properties of living systems. The opportunity to sample another "world" to get at these basic questions is of enormous importance to biology.

APPROACHES TO BIOLOGICAL INSTRUMENTATION

Over the years, numerous suggestions have been proposed for the purpose of

detecting biological activity on Mars (for a review, see Bruch, 1966). These have ranged from imaging techniques (Soffen, 1963) through chemical and biochemical analyses (Young, 1969) to direct tests for the growth of organisms (Vishniac, 1960). The basic problem is that of trying to make measurements to search for an organism whose properties are unknown.

The various procedures and tests that have been proposed all measure some attribute of living organisms. In general, the major characteristics of living organisms that have come to be regarded as fundamental, and which could be subjected to analytical instrumentation, are concerned with metabolic activity and growth.

Choosing the most effective means to measure metabolism and growth poses serious problems, especially as they are to be conducted with fragmentary knowledge of the local environmental characteristics of the Martian surface. Based on one set of assumptions, it would seem reasonable to measure endogenous metabolism in a soil sample; that is, metabolism in the absence of any externally added nutrients, or even of water. On the other hand, we know that many terrestrial organisms are ordinarily dormant in the soil until suitable substrates are supplied, and, until these are added, very little activity can be detected in such samples. On Earth, the availability of moisture often determines whether or not microorganisms can be detected in soils.

Based on other assumptions, however, the addition of organic substrates might be regarded as of little value since the particular compounds chosen might simply not be metabolizable by Martian organisms. Indeed, certain compounds geocentrically chosen to stimulate metabolic activity of Martian organisms might, instead, prove to be toxic to them. Thus, also for water; while it is essential to the survival of all terrestrial organisms, these vary considerably in their tolerance to aqueous environments. Bacteria and algae from saline environments often fail to grow, or are killed, in dilute media.

THE VIKING BIOLOGY PAYLOAD

It should be emphasized first that many measurements made by the Viking payload are of biological importance, as, for example, the water measurements, imaging, and even the meteorological measurements. However, in particular, the concomitant molecular analysis experiments are indispensable to the implementation of the scientific objectives of the Viking biological investigation now under discussion. Correlative evidence for or against the presence of Martian organisms might be obtained from the atmospheric measurements in the molecular analysis experiments. Lovelock (1965) has pointed out that the coexistence of both oxidized and reduced gases in the atmosphere is indicative of the presence of living organisms. Other, possibly unpredictable, paradoxes might have to be resolved by hypothesizing a living metabolism (cf. Lederberg, 1965).

Several direct biological tests were selected here because each was based on different assumptions about the probable nature of Martian organisms. The four different analyses are discussed in detail in the following papers, each predicated upon

measurement of some aspect of metabolic activity. Three of the procedures—the test for assimilation of CO and CO₂ (I), the measurement of labeled carbon dioxide released from labeled substrates (II), and the gas exchange measurements (III)—can, in principle, detect “resting” metabolism, although all of them are improved by any growth of organisms in the test samples. Experiment I is performed with the minimum addition of external substances, only radioactive CO₂ and CO (and possibly water vapor) being added to the samples. In II, extremely dilute solutions of labeled organic matter will be added to Martian soil samples, under conditions that just barely moisten the samples. Experiment III provides a mixture of a large number of organic compounds to the sample, and is performed in the presence of greater amounts of water than the other two measurements. The light scattering experiment (IV) requires the growth of organisms in the sample. Here, only water is added to the soil sample, resulting in a concentrated suspension. Those materials that can be extracted by the water, or which are

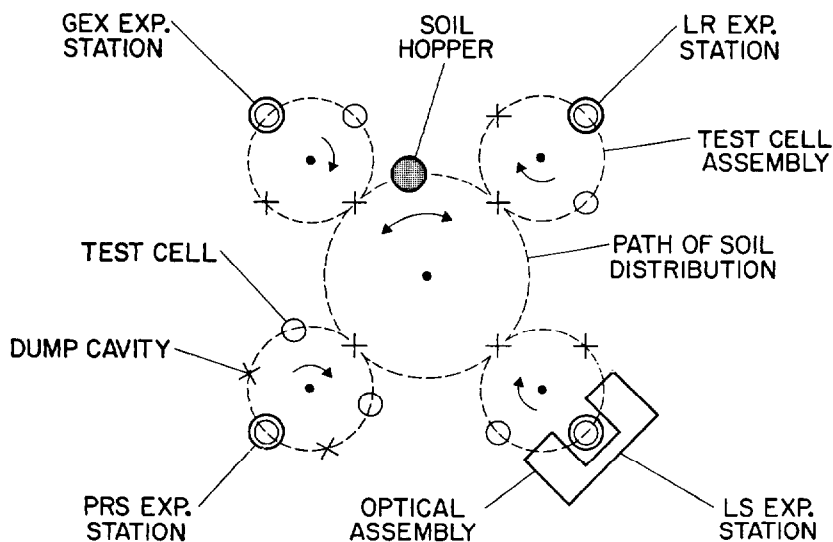


FIG. 1. Soil distribution system. The soil sample (sized under 2mm) is received from the lander distribution system into a hopper where it falls by gravity into metering cups associated with each experimental test station. The rotation of the soil distribution assembly causes, via an engagable Geneva mechanism, rotation of the individual test chamber assemblies, dumping the soil from the metering cavity into an active test cell, a control test cell, or a dump cavity.

otherwise available in the suspension of Martian surface material, serve as potential substrates for the growth of indigenous organisms. Thus, the experiments range in gradations from dry to wet and from autotrophic to heterotrophic, each optimized for different nutritional or environmental requirements.

A soil distribution assembly common to all four assay systems will receive a bulk quantity of soil from the Viking lander and ration prescribed amounts to each of four stations (Fig. 1). All four tests, thus, will be carried out on the same soil samples. The design of the instrument provides for nine test cells, three for the carbon assimilation experiment (also called the pyrolytic release experiment), and two each for the other three determinations. With such an arrangement, it will be possible to conduct at least three separate 15-day tests over the nominal 90-day lander lifetime and one control test at each of the four experiment stations. Controls will be performed in the event that any of the tests gives a positive response. For the controls, it is planned to heat the soil

samples to 160°C for 3 hr and then to test them as usual.

A general schematic of the integrated instrument is shown in Fig. 2. Martian gas will be pumped in to each of the four stations before incubation of the samples and also during certain purging operations. Two injectors will supply radioactive gas and water vapor for use in I. Three liquid injectors will serve the remaining experiments. The instrument will contain two β -particle detection chambers for counting ^{14}C ; one for Experiment I, and the other for Experiment II. These chambers are diffused junction silicon detectors with energy discrimination thresholds between 40 and 80 keV. In the gas exchange experiment, a thermal conductivity detector will indicate each gas and determine its concentration. Brief details of current designs for the four experiments are given in Figs. 3 through 6.

The integrated electrical subsystem will provide all sequence control, power distribution, and regulation, as well as scientific and engineering data collection and storage functions. The sequence of each determina-

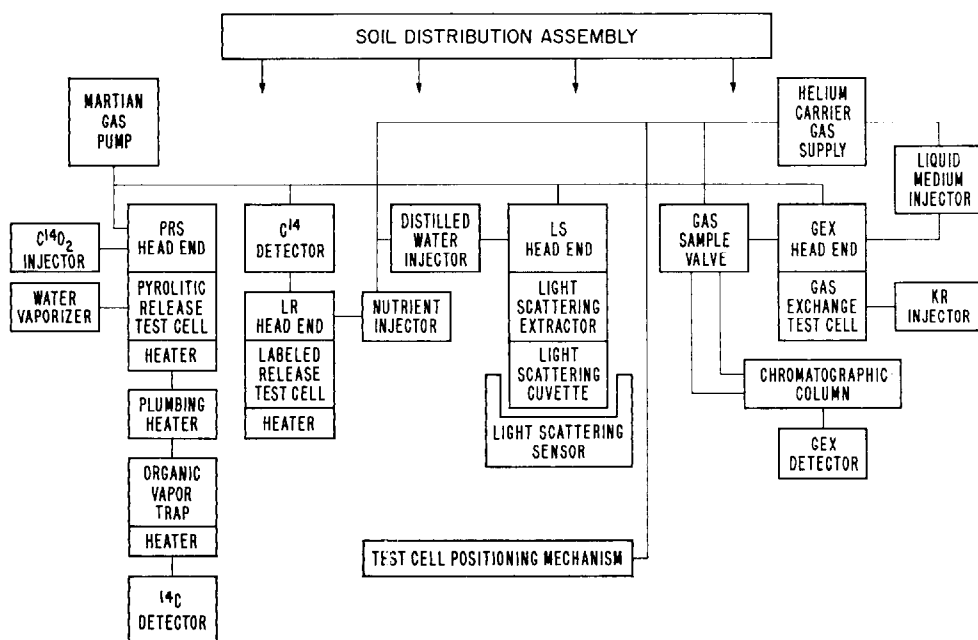


Fig. 2. Generalized schematic of the Viking biology instrument.

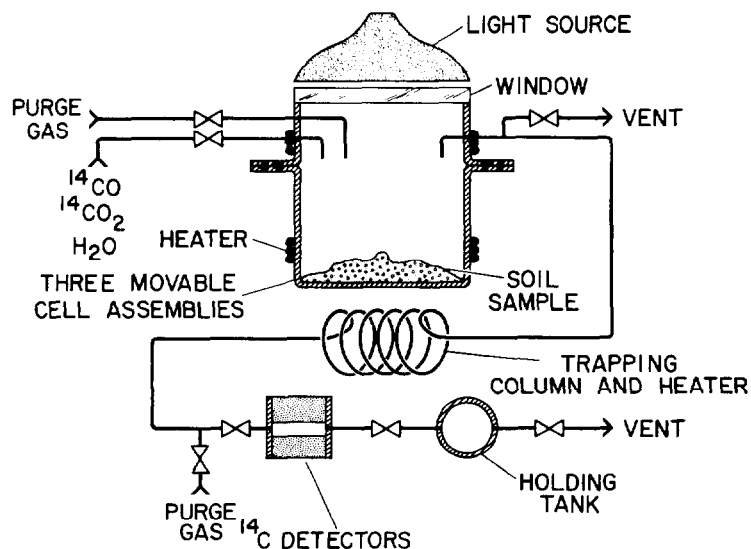


FIG. 3. Carbon assimilation (Experiment I). The soil sample is placed in one of three movable incubation cells under an atmosphere containing labeled carbon dioxide and carbon monoxide (addition of water vapor is optional upon command). The samples are incubated for several days under light from a xenon lamp, filtered to remove energy below 310 nm. At the end of the incubation, the headspace gases are flushed from the chamber and an acceptable background is counted by the detectors. The sample is then pyrolyzed to 600°C, and the evolved gases are swept onto the copper oxide trapping column held at 120°C. The carbon dioxide liberated in the pyrolysis passes through the column to both the detector and holding chamber for counting. The system is then purged, background counted, and the trapped organics are liberated from the column by heating the column to 700°C. During this process, the organics are oxidized and transferred to the detector chamber for counting.

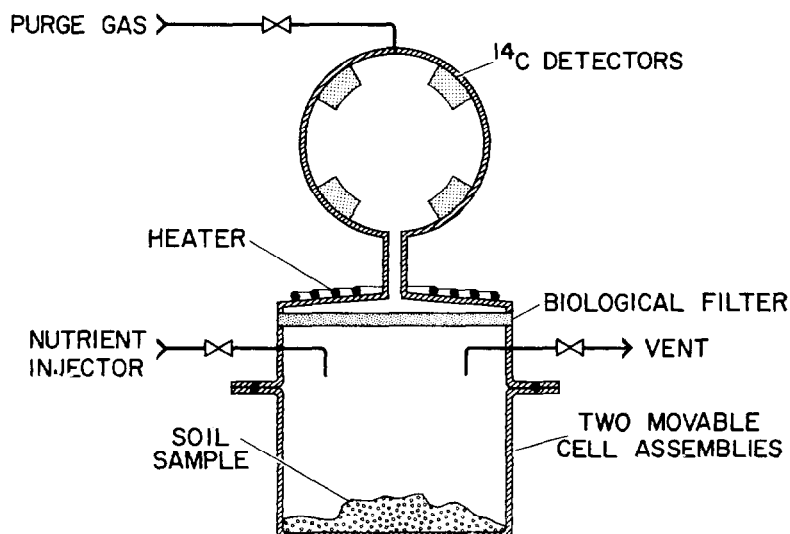


FIG. 4. Label release (Experiment II). The soil sample is placed in one of two movable incubation chambers. The stored nutrient and the incubation chamber are both flushed, after which, the nutrient is injected onto the soil. The evolution of labeled gas is monitored in the detector chamber.

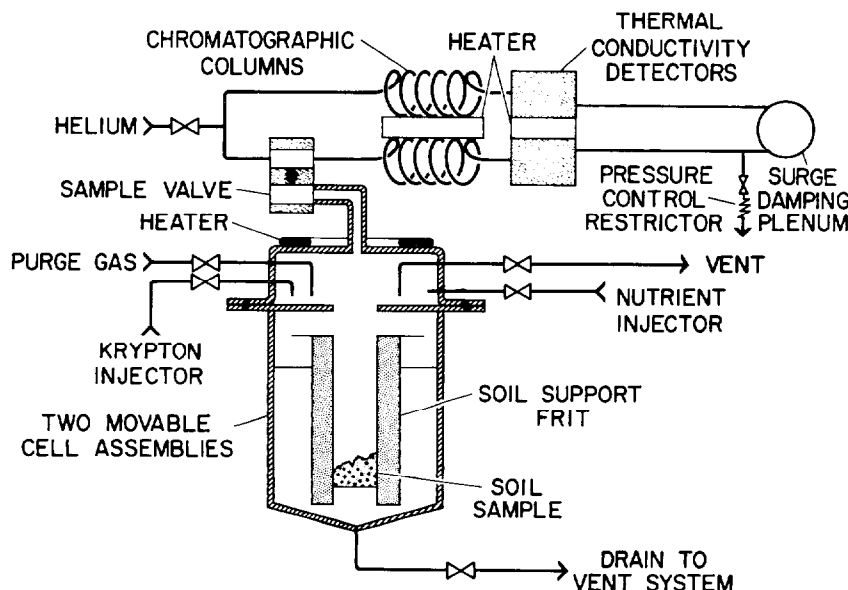


FIG. 5. Gas exchange (Experiment III). The soil is placed in one of two movable incubation chambers. After purging of the system, the nutrient is added in a manner that does not submerge the entire soil sample. Krypton is added as an internal standard. Exchange of gas into the headspace is sampled by the gas sampling valve which removes a $100\ \mu\text{l}$ sample and places it in the helium carrier stream. The gaseous components of the sample are resolved on the chromatograph column and, upon reaching the detector, yield a signal that when compared with the pure helium reference side is proportional to the gas concentration. The retention time of the various gaseous components is used to identify the various gases.

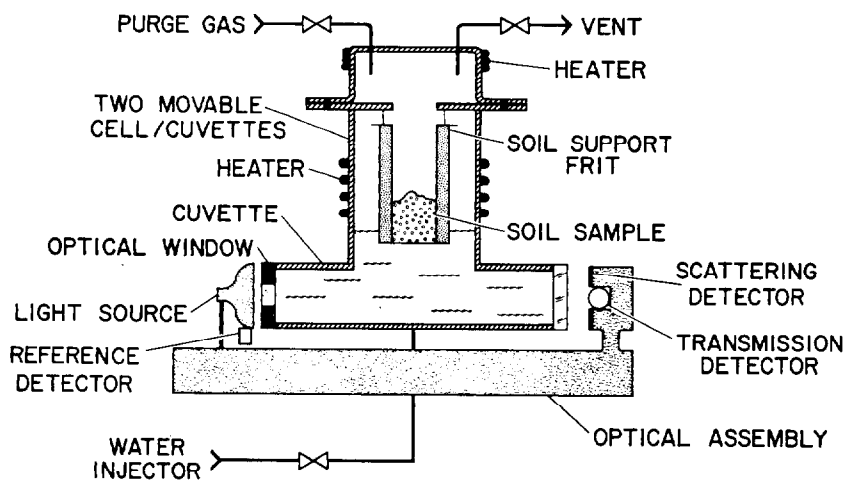


FIG. 6. Light scattering (Experiment IV). The soil is placed in one of two incubation chambers into a porous frit cup. Water is then added to the chamber so as not to totally submerge the sample and is periodically monitored thereafter for changes in light scattering and light transmission through the optical cuvette portion of the chamber. The reference beam is also measured. The entire optical assembly can swing away to allow rotation of the incubation cells into position.

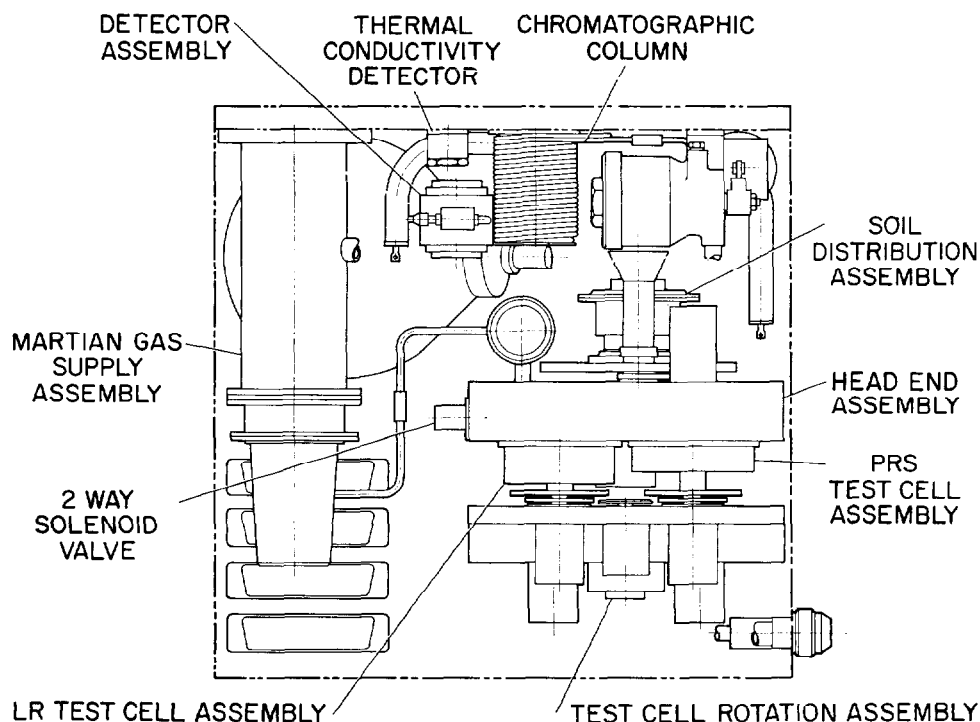


FIG. 7. Viking biology instrument. Side view packaging drawing.

tion will be fixed by the instrument sequencer; however, sequence segments may be initiated or terminated by command. The instrument sequencer can be updated from the lander, and the data can be transmitted to the main lander memory several times per day. The combined, integrated, instrument (Fig. 7) is being designed to occupy a volume of 1100 cu in., to weigh 18.9 lb, and have overall dimensions of $9.5 \times 10 \times 11.5$ in.

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